

# THE EFFECT OF NOVEL ANKLE-REALIGNING SOCKS ON DYNAMIC POSTURAL STABILITY IN INDIVIDUALS WITH CHRONIC ANKLE INSTABILITY

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## ABSTRACT

**Background:** A dynamic postural stability deficit has been suggested to be present in individuals with chronic ankle instability (CAI). Interventions to improve postural control in individuals with CAI have been reported, but they required a long period of and compliance with interventions.

**Purpose:** To examine the effect of novel ankle-realigning socks on dynamic postural stability in individuals with CAI using the star excursion balance test (SEBT).

**Study Design:** Case-control study.

**Methods:** Twenty-eight control and 22 subjects with CAI (who were tested in both barefoot and with socks) were enrolled. The weight-bearing ankle dorsiflexion range of motion (DF-ROM) and SEBT were measured in the control group, the barefoot CAI group, and the CAI with socks group. In addition, subjective ankle instability during SEBT was measured using a visual analog scale (0 - 100).

**Results:** DF-ROM was  $48.3 \pm 7.4^\circ$  in the control group,  $43.3 \pm 8.0^\circ$  in the barefoot CAI group, and  $45.7 \pm 6.8^\circ$  in the CAI with socks group. DF-ROM was significantly less in the barefoot CAI group than in the control group. The SEBT scores were significantly less in the barefoot CAI group than in the control group in all directions. The SEBT score was significantly larger in the CAI with socks group than in the barefoot CAI group in the posteromedial, posterior, and posterolateral directions. In addition, there were no significant differences between the control group and the CAI with socks group in six directions.

**Conclusion:** Wearing the novel ankle-realigning socks immediately improved dynamic postural stability as measured by the SEBT and subjective ankle instability in individuals with CAI.

**Level of Evidence:** Level 3b

**Keywords:** chronic ankle instability, dorsiflexion range of motion, lateral ankle sprain, star excursion balance test

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**Conflict of Interest:** This novel socks used in this study were provided by the company owned by Kazuyoshi Gamada. Other authors declare that there are no conflicts of interest related to this study.

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## INTRODUCTION

Lateral ankle sprain is one of the most common injuries in competitive sports and recreational activities.<sup>1</sup> Ankle injuries account for 10 to 30% of all athletic injuries and 40-56% of injuries in certain sports.<sup>1</sup> The recurrence rates for lateral ankle sprains have been reported to be more than 50%,<sup>2-4</sup> and repeated lateral ankle sprains potentially leading to chronic ankle instability (CAI).<sup>5</sup> Thus, because of the economic and social costs of lateral ankle sprains,<sup>6</sup> prevention of lateral ankle sprains and CAI is an important issue.

The postural control deficit in individuals with CAI has been extensively investigated,<sup>7</sup> and the Star Excursion Balance Test (SEBT) has often been used to examine dynamic postural control.<sup>8</sup> The SEBT involves having the subject maintain a single-leg stance while performing a maximal reach excursion with the contralateral limb in each of eight directions of a star on the floor.<sup>9,10</sup> In a meta-analysis, individuals with CAI showed decreased dynamic postural control on the SEBT or time to stabilization by force plates,<sup>11</sup> and balance training for the improvement of postural control for individuals with previous ankle sprains is important to prevent recurrent lateral ankle sprains.<sup>12</sup> Some authors have reported the effects of interventions to improve postural control in individuals with CAI using a balance board or foot orthotics. Sefton et al.<sup>13</sup> showed improvement of maximal reach distances in individuals with CAI after 6 weeks of balance board training. Sesma et al.<sup>14</sup> reported similar results after four weeks of foot orthotic use. However, these interventions had some issues because they required a long period and compliance.

Various factors such as joint kinematics and muscle activity have been shown to be related to the results of SEBT.<sup>15,16</sup> In CAI, abnormal ankle joint alignment and kinematics can occur,<sup>17,18</sup> which may contribute to decreased postural stability.<sup>16</sup> Researchers have reported that talocrural joint mobilization for joints with CAI improved dynamic postural stability.<sup>19</sup> The improvement is believed to be attributed to posterior gliding of the talus relative to the tibia during the SEBT, which can be achieved by taping to induce posterior gliding of the talus. To avoid using technique-dependent taping in this study, a novel functional soft brace in the form of socks (novel



**Figure 1.** Novel ankle-realigning socks (Realine socks®).

ankle-realigning socks) was used as a new intervention for CAI (Realine socks®, GLAB Corp, Hiroshima, Japan, Figure 1). These novel ankle-realigning socks are designed to normalize talocrural joint kinematics by inducing posterior gliding of the talus without restricting joint mobility by using a material with high and low elasticity in parts, as with taping as reported in the past.<sup>20</sup> Wearing the socks is very simple and does not require any special technique as is required in taping. This novel intervention may induce normal kinematics of the talocrural joint and improve postural stability.

Thus, the objective of this study was to examine the effect of novel ankle-realigning socks on dynamic postural stability in individuals with CAI using the star excursion balance test (SEBT).

The authors hypothesized that the ankle-realigning socks would immediately improve dynamic postural stability in individuals with CAI.

## METHODS

### Participants

The protocol of this case-control study was approved by the Institutional Review Board at Hokkaido Chitose College of Rehabilitation, and the purpose of this study was to compare dynamic postural stability in individuals with CAI wearing a novel device and healthy individuals. The subjects were recruited by

questionnaires of medical college students in January 2015. Informed consent was obtained from all subjects prior to participation. Inclusion criteria and exclusion criteria for the CAI group conformed to the criteria proposed by the International Ankle Consortium (IAC).<sup>21</sup> In addition, Identification of Functional Ankle Instability (IdFAI)<sup>22</sup> was used to assess subjective ankle instability as recommended in the IAC criteria. The inclusion criterion for the control group was no ankle sprain history. Exclusion criteria for the control group were as follows: (a) history of surgery or fractures of the lower extremity; (b) pain in the lower extremity; (c) history of cerebrovascular disorders or neuropathy that affects balance; or (d) use of any medications that could affect balance.

Twenty-eight control (28 feet; male 16/female 12; mean  $\pm$  SD age: 20.8  $\pm$  2.3 years) and 22 CAI (26 feet; male 12/female 10, mean  $\pm$  SD age: 20.8  $\pm$  2.4 years) subjects participated in this study. There were no significant differences in their general characteristics (Table 1). The measurement limbs were the right in 21 and the left in 7 in the control group, and the right in 18 and the left in 8 in the CAI group. The average value of the IdFAI score of the CAI group was 18.1 (11-30).

### Ankle Realigning Socks

The ankle-realigning socks were designed to control talocrural joint motion, including posterior gliding of the talus during dorsiflexion and anterior gliding during plantar flexion, while preventing inversion (Figure 1). The structure of the socks was designed based on the authors original taping structure often used for athletes to accelerate return to play after ankle injury. It includes two bands medially and two bands laterally. Medially, the first band pulls the sole of the foot at the medial arch toward the

medial malleolus, located posterior to the talocrural dorsiflexion/plantar-flexion joint axis. Therefore, it is in greater tension with ankle dorsiflexion, which helps posterior gliding. The second band pulls the medial heel to the medial malleolus, inducing calcaneal external rotation to balance the first band in the horizontal plane. By combining the two bands, the dorsiflexion/plantar-flexion joint axis is stabilized medially. Laterally, the third band pulls the lateral calcaneus to the lateral malleolus to prevent calcaneal inversion. The fourth band connects the 5th metatarsal to the region 10 cm proximal to the inferior tip of the lateral malleolus, preventing inversion during plantar flexion. The four bands together are thought to increase the range of motion in the neutral ankle position and improve stability at maximal dorsiflexion due to bony conformity. Patients with previous injuries of the anterior talofibular ligament experience an immediate reduction of pain, which suggests that the socks help reduce the tension of the ligament by realigning the talus posteriorly. A kinematic study is currently underway to support these speculations and observations.

### Protocol

The measurements were performed in the order of (1) trochanter malleolar distance (TMD), (2) weight-bearing ankle dorsiflexion range of motion (DF-ROM), and (3) SEBT. The CAI group underwent the SEBT barefoot on the affected ankle (barefoot CAI group), and the control group was tested barefoot on the randomly selected side (control group). Then, subjects with CAI underwent the DF-ROM and SEBT the next day wearing the ankle-realigning socks (CAI with socks group). After putting on the socks, all subjects walked for five minutes to fit the socks to the feet. In order to eliminate the

**Table 1.** General characteristics of the participants, reported as means  $\pm$  SD.

Variable	Control (n = 28)	CAI (n = 22)	95% CI
Age (y)	20.8 $\pm$ 2.3	20.8 $\pm$ 2.6	-1.3, 1.4
Height (cm)	165.1 $\pm$ 6.7	165.6 $\pm$ 6.9	-4.4, 3.4
Mass (kg)	58.3 $\pm$ 8.1	62.6 $\pm$ 10.0	-9.4, 0.9

influence of walking, all subjects walked for the same amount of time even before barefoot measurements. The TMD was measured three times in the supine position, and the average value was calculated. The DF-ROM was measured according to the technique reported by Kobayashi et al.<sup>23</sup> Each subject was asked to place the foot perpendicular to a wall in a lunge position and bend the forward knee toward the wall, without lifting the heel, until the maximum range of ankle dorsiflexion was reached. During the testing, the subject was instructed to align and maintain the orientation of the forward knee and toe. The examiner measured the ankle dorsiflexion angle three times using an inclinometer tightly pressed against the anterior aspect of the tibia, and the average value was calculated. The SEBT was measured according to the previous study (Figure 2).<sup>8</sup> Measurements were performed three times after four practice times in each direction to avoid learning effects. The average value of three times was then calculated. After the measurements were completed, subjective ankle

instability was measured with a visual analog scale (VAS, 0-100). At that time, subjects were instructed to self-evaluate the “fear of twisting the ankle” and the “feeling of ankle instability” of the pivot foot. The value obtained by dividing the average distance in each direction by the TMD was defined as the SEBT score. The first measurement direction of the SEBT was set randomly, and then subsequent measurements were performed counterclockwise.

### Statistical analysis

All data were confirmed to be normally distributed by the Shapiro-Wilk test. The general characteristics of the subjects were compared using the independent *t*-test. For comparisons among the three groups (control/barefoot CAI/CAI with socks) of the DF-ROM and SEBT score, one-way analysis of variance was performed. Similarly, one-way analysis of variance was used to compare the VAS in each direction of SEBT in the control group. Two-way repeated measures analysis of variance (direction × socks) was used to compare the VAS of the subjects with CAI. Tukey’s HSD test was used as a post hoc test. To assess the clinical significance of the data, effect sizes ( $\eta$ ) were calculated and interpreted according to Cohen (small,  $< .01$ ; medium, 0.02 to 0.13; large,  $\geq .14$ ).<sup>24</sup> The minimum effect size of the SEBT score in CAI was 0.67 in a similar previous study.<sup>25</sup> Statistical power analysis based on this value showed that nine or more subjects were required in each group ( $\alpha = .05$ ,  $\beta = .20$ ). All data were analyzed using the Statistical Software Package for the Social Sciences (SPSS ver.19, SPSS Inc., Chicago, IL, USA). Differences were considered significant at  $p < .05$ .

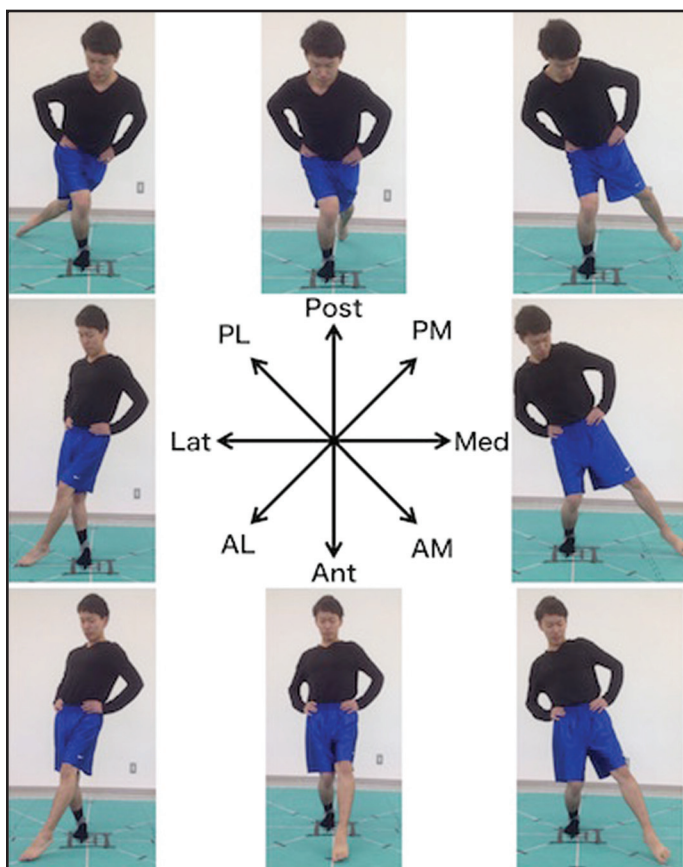
## RESULTS

### DF ROM

DF-ROM was  $48.3 \pm 7.4^\circ$  in the control group,  $43.3 \pm 8.0^\circ$  in the barefoot CAI group, and  $45.7 \pm 6.8^\circ$  in the CAI with socks group. DF-ROM was significantly smaller in the barefoot CAI group than in the control group ( $p = .033$ ). The effect size for DF-ROM was 0.11 or medium (Table 2).

### SEBT score

The SEBT score was significantly smaller in the barefoot CAI group than in the control group in all



**Figure 2.** Star Excursion Balance Test, used for assessment.

directions ( $p < .05$ ). The scores in the posteromedial (PM), posterior (Post), and posterolateral (PL) directions were significantly larger in the CAI with socks group than in the barefoot CAI group. In addition, there were no significant differences between the control group and the CAI with socks group in six directions (anterolateral (AL), medial (Med), PM, Post, PL, lateral (Lat)). The effect size for the SEBT score was medium to large (AL; 0.11, Ant; 0.14, AM; 0.16, Med; 0.15, PM; 0.18, Post; 0.21, PL; 0.21, Lat; 0.10) (Table 3).

### Subjective ankle instability

There was no significant difference in subjective ankle instability among SEBT directions in the

control group (Table 4). In contrast, interaction was observed in the comparison of the barefoot CAI group and the CAI with socks group ( $p = .028$ ). The VAS scores in all directions in the subjects with CAI were significantly decreased by wearing socks (Table 5). PL was significantly greater than Med, PM, and Post (Med  $p < .001$ , PM  $p = .003$ , Post  $p = .002$ ), Lat was significantly greater than Med ( $p = .001$ ), and AL was significantly greater than Med ( $p = .001$ ) in the barefoot CAI group (Table 5). In the CAI with socks group, PL was significantly greater than Med ( $p = .002$ ), and Lat was significantly greater than Med and PM (Med  $p = .009$ , PM  $p = .042$ ) (Table 5). The effect size ( $\eta$ ) for the main

**Table 2.** Weight-bearing DF-ROM (Mean  $\pm$  SD).

	Control	Barefoot CAI	CAI with socks	Effect size ( $\eta$ )
DF-ROM ( $^{\circ}$ )	48.3 $\pm$ 7.4	43.3 $\pm$ 8.0 *	45.7 $\pm$ 6.8	0.11
* DF-ROM is significantly smaller in the barefoot CAI group than in the control group ( $p = 0.033$ ). DF= dorsiflexion; ROM= range of motion; CAI= chronic ankle instability				

**Table 3.** SEBT Scores, percentage to trochanter malleolar distance (Mean  $\pm$  SD).

Direction	Control	Barefoot CAI	CAI with socks	Effect size ( $\eta$ )
AL	68.6 $\pm$ 7.4	62.9 $\pm$ 7.4 *	64.7 $\pm$ 7.2	0.11
Ant	72.8 $\pm$ 6.4	67.5 $\pm$ 7.0 *	67.9 $\pm$ 6.3 *	0.14
AM	81.5 $\pm$ 6.1	75.7 $\pm$ 6.5 *	77.1 $\pm$ 6.2 *	0.16
Med	94.2 $\pm$ 7.5	87.4 $\pm$ 7.6 *	89.4 $\pm$ 7.4	0.15
PM	109.7 $\pm$ 9.1	101.2 $\pm$ 8.2 †	105.2 $\pm$ 8.4	0.18
Post	117.1 $\pm$ 11.3	105.7 $\pm$ 11.3 †	111.7 $\pm$ 10.7	0.21
PL	105.7 $\pm$ 12.6	92.0 $\pm$ 12.8 †	99.5 $\pm$ 11.3	0.21
Lat	67.0 $\pm$ 8.3	60.2 $\pm$ 8.6 *	61.4 $\pm$ 9.4	0.10
* The SEBT score is significantly smaller than in the control group ( $p < 0.05$ ). † The SEBT scores is significantly less in the barefoot CAI group than in the control group and the CAI with socks groups ( $p < 0.05$ ). SEBT= Star Excursion Balance Test; CAI= chronic ankle instability; AL= anterolateral; Ant= anterior; AM= anteromedial; Med= medial; PM= posteromedial; Post= posterior; PL= posterolateral; Lat= lateral				

**Table 4.** VAS for subjective ankle instability of the control group during SEBT (Mean  $\pm$  SD).

Direction	VAS
AL	22.2 $\pm$ 21.6
Ant	18.7 $\pm$ 21.7
AM	16.6 $\pm$ 18.3
Med	12.5 $\pm$ 13.0
PM	13.1 $\pm$ 14.8
Post	13.3 $\pm$ 15.1
PL	20.1 $\pm$ 20.1
Lat	21.1 $\pm$ 23.7

There was no significant difference among the SEBT directions. VAS= visual analog scale; AL= anterolateral; Ant= anterior; AM= anteromedial; Med= medial; PM= posteromedial; Post= posterior; PL= posterolateral; Lat= lateral

effects (direction/socks) was 0.11 and 0.13 respectively, or medium.

## DISCUSSION

The objective of this study was to examine the effect of ankle-realigning socks on dynamic postural stability in subjects with CAI. The results of this study demonstrated that DF-ROM and the SEBT scores were significantly less in the barefoot CAI group than in barefoot control subjects. When using socks, the SEBT score improved instantly in the PM, Post, and PL directions, and the subjective ankle instability during SEBT was also significantly improved.

Dynamic postural stability in individuals with CAI has been considered in several studies. Gribble et al.<sup>26</sup> reported decreased SEBT scores in the Ant, Med, and Post directions in individuals with CAI.

**Table 5.** VAS for subjective ankle instability of CAI groups during SEBT(Mean  $\pm$  SD).

Direction	Barefoot CAI (Mean $\pm$ SD)	CAI with socks (Mean $\pm$ SD)	Socks (p-value)	Direction barefoot CAI (p-value)	Direction CAI with socks (p-value)
AL	43.5 $\pm$ 27.2	29.7 $\pm$ 19.1	0.002	> Med 0.012	
Ant	35.5 $\pm$ 23.3	23.9 $\pm$ 16.2	0.004		
AM	36.3 $\pm$ 21.3	25.3 $\pm$ 17.5	0.006		
Med	27.7 $\pm$ 19.5	19.0 $\pm$ 13.2	0.001	< AL 0.012 < PL 0.000 < Lat 0.001	< PL 0.002 < Lat 0.009
PM	30.8 $\pm$ 23.5	22.1 $\pm$ 12.7	0.026	< PL 0.003	< Lat 0.042
Post	33.3 $\pm$ 23.0	25.0 $\pm$ 17.2	0.037	< PL 0.002	
PL	50.8 $\pm$ 22.8	29.8 $\pm$ 17.0	< 0.000	> Med 0.000 > PM 0.003 > Post 0.002	> Med 0.002
Lat	49.0 $\pm$ 25.5	32.0 $\pm$ 17.6	< 0.000	> Med 0.001	> Med 0.009 > PM 0.042

VAS= visual analog scale; CAI= chronic ankle instability; SEBT= Star Excursion Balance Test; AL= anterolateral; Ant= anterior; AM= anteromedial; Med= medial; PM= posteromedial; Post= posterior; PL= posterolateral; Lat= lateral

Similarly, decreases in the SEBT scores in the AM, Med, PM, and PL directions were reported by other previous studies.<sup>9,27,28</sup> However, these studies differed in the selection criteria for CAI.<sup>21</sup> The present study met IAC criteria and all individuals with CAI demonstrated decreased SEBT scores.

The effects of interventions aimed at improving dynamic postural stability in individuals with CAI have been verified by other authors (Table 6). These authors reported significant improvements in SEBT scores after four to six week interventions.<sup>13,14,29,30</sup> Although the results of the present study supported these previous results, the present study included only short-term follow-up. This suggests that the novel ankle-realigning socks have the effect of improving immediate and short-term dynamic postural stability in individuals with CAI within a short period of time. Meanwhile, in the present study, there was no significant improvement in the anterior SEBT direction, despite significant improvement in previous studies. This may be because no significant improvement was observed in ankle DF-ROM, which was positively correlated with the anterior SEBT direction.<sup>31</sup> Earl and Hertel<sup>32</sup> reported that the muscle activity of the vastus medialis was related to the anterior SEBT direction. However, this study

did not measure muscle activity anywhere in the lower extremity, thus, the effect of muscle activity is unknown. It is unknown whether after a longer period, of sock wearing there may be a significant change in the anterior SEBT direction, and, therefore, further study is necessary.

Some researchers have shown that DF-ROM<sup>15,25,31</sup> and hip/knee joint kinematics<sup>16,33</sup> affect the SEBT score. In the present study, the barefoot CAI group had significantly decreased DF-ROM compared to the control group, and this may have affected the results of the SEBT score. In addition, subjective ankle instability increased in the PL, Lat, and AL directions in the barefoot CAI group, which may be due to increased inversion necessary to increase these tasks. When individuals with CAI wore the ankle-realigning socks, subjective ankle instability was significantly decreased. Although subjective ankle instability was decreased, there was no limitation on DF-ROM by wearing the socks, but rather a slight improvement was observed (barefoot CAI,  $43.3 \pm 8.0^\circ$ ; CAI with socks,  $45.7 \pm 6.8^\circ$ ). This may suggest that ankle-realigning socks changed not only talocrural joint kinematics, but sensory awareness, proprioception, or muscle activity. The authors need to verify detailed mechanisms of action of the novel socks, by

**Table 6.** Intervention intended to increase dynamic postural stability (SEBT) in CAI.

Study	Number of subjects	Intervention	Frequency Duration	Results (SEBT)
Sesma, 2008	34	foot orthotics	4-8 hours/day 4 weeks	significantly improved (all 8 directions)
Sefton, 2011	12	balance training	3 sessions/week 6 weeks	significantly improved (Ant / AM / PM)
Schaefer, 2012	36	balance training soft-tissue mobilization	2 sessions/week 4 weeks	significantly improved (Ant / PM / PL)
Cruz-Diaz, 2015	70	multi-station balance training	- 6 weeks	significantly improved (Ant / PM / PL)
Current study	22	novel ankle-realigning socks	- 5 minutes	significantly improved (PM / Post / PL)
CAI= Chronic ankle instability; Ant= anterior; AM= anteromedial; PM= posteromedial; Post= posterior; PL= posterolateral; SEBT= star excursion balance test				

analysis of joint kinematics (e.g. 3D-to-2D analysis technique) or electromyography to explore this possibility. This reduction of subjective ankle instability induced by the ankle-realigning socks may have increased dynamic stability and mobility of the lower limb joints and led to an improved SEBT score.

The subjects in the present study were recruited according to IAC criteria.<sup>21</sup> In addition, the SEBT and DF-ROM measurements were performed according to methods proven highly reliable in previous studies.<sup>8,23</sup> Accordingly, this study was carried out with high internal validity. As for external validity, since this study included only young college students, these results may not be applicable to athletes, adolescents, or elderly persons.

This study had some limitations. This study did not investigate muscle activity or joint kinematics that may affect the SEBT score.<sup>15,16</sup> In addition, the effects of the ankle-realigning socks on ankle kinematics, sensory awareness, and lower leg muscle activity are unknown, and the mechanism of the effect of the socks remains speculative. Accordingly, it is necessary to determine the mechanism of action. Moreover, this study considered only the immediate effect; the sustainability of the effect is unknown.

## CONCLUSION

The results of the current study indicate that in individuals with CAI meeting IAC criteria, DF-ROM and the SEBT scores of all eight directions were significantly decreased compared to healthy subjects. In addition, subjective ankle instability was increased during lateral reach in those with CAI. The results indicate that wearing the ankle-realigning socks immediately significantly improved dynamic postural stability and subjective ankle instability in subjects with CAI in the short term. A future study may focus on the mechanism of the effect of the ankle-realigning socks with a larger sample size for appropriate power.

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